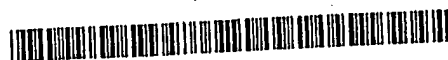


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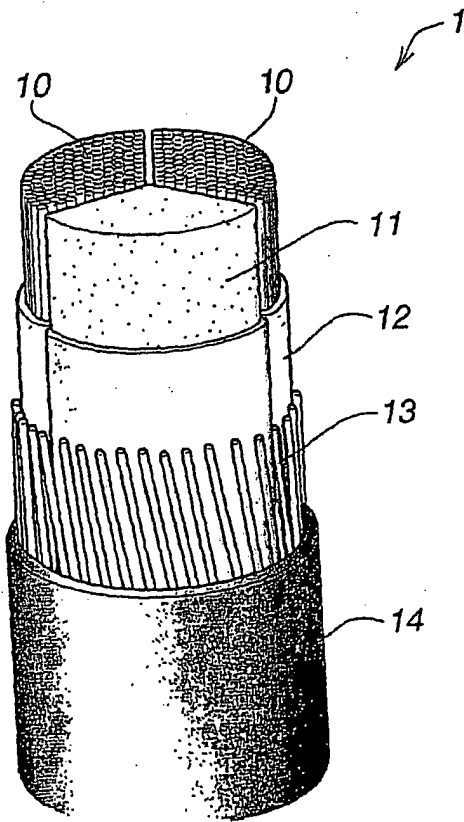
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(54) Title: **POWER CABLE**

(57) Abstract: A power cable containing at least one conductor comprising individual nanostructures that are substantially homogeneously dispersed in a matrix.



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## **Power cable**

### **TECHNICAL FIELD**

The present invention relates to a power cable. More particularly the invention concerns new alternatives for a power cable's conductor material, the design of a power cable containing the new conductor material, current control in said power cable and a method for it's production.

### **BACKGROUND OF THE INVENTION**

Copper and aluminium are used as conductor materials in most power cables today. Copper for electrical use is manufactured by an electrolytic process resulting in at least 99.9% purity. Copper has very good electric conductivity, is easy to connect and has high tensile strength. The problem with using copper is that the availability of raw material is limited and copper is listed as a toxic metal. Aluminium used as conductor material is 99.7% pure and is produced electrolytically from bauxite. The technical disadvantages of aluminium compared with copper, such as inferior conductivity, cold creep and a tendency to oxidise, are counterbalanced by commercial advantages such as low and stable price and good availability. The disadvantages mentioned also make aluminium unsuitable for use in small conductors with an area up to 25mm<sup>2</sup>. Another disadvantage is that large amounts of energy are consumed in the production of aluminium. There are therefore good reasons for seeking alternative materials for conductors.

In 1985 a third allotrope of carbon was discovered. Hollow spherical/tubular molecules consisting of  $sp^2$ -hybridised carbon arranged in hexagons and pentagons, were identified as products of experiments in which graphite was vaporised by a laser. This discovery was published in "C<sub>60</sub>: Buckminsterfullerene", Kroto H.W, Heath J.R, O'Brien S.C, Curl R.F and Smalley R.E, Nature vol. 318, p162, 1985. Such molecules consist of at least 32 carbon atoms and the most common and stable form of these structures is a spherical molecule consisting of 60 carbon atoms. These hollow spherical/tubular molecules are called fullerenes. A spherical molecule consisting of 60 carbon atoms, C<sub>60</sub>, is called a "buckminster fullerene" or a "bucky ball". In the C<sub>60</sub> molecule each carbon atom is bonded to three other carbon atoms and the binding is mainly  $sp^2$  with an  $sp^3$  contribution.

Fullerenes exist as open tubes 0.7 to 1.5 nm in diameter and at least 20  $\mu\text{m}$  in length and as closed tubes having hemispherical end-caps containing six pentagons at both ends. Such fullerenes are also called carbon nanotubes. Carbon nanotubes can exist in two highly symmetrical structures namely "zig-zag" and "armchair" structures. These names arise from the pattern which is seen around a carbon nanotube's periphery if it is cut in a direction across its length i.e. a zig-zag pattern or a pattern which looks like the seat and arm rests of an armchair. In practice most carbon nanotubes do not have these highly symmetrical structures but structures consisting of hexagons oriented in a helical formation around the axis of the carbon nanotube. A designation system for carbon nanotubes is described in "Electronic Structure of Chiral Graphene Tubules" by Saito R, Fujita M, Dresselhaus G, and Dresselhaus M.S, Appl. Phys. Lett. 60, pp2204-2206, 1992.

The helical structure and diameter of a carbon nanotube can be represented by the vector,  $C$ , connecting two crystallographically equivalent sites on a sheet of graphite, where;

$$C = na_1 + ma_2 \equiv (n,m)$$

and  $n$  and  $m$  are integers where  $n \geq m$ , and  $a_1$  and  $a_2$  are the graphite structure's unit vectors. A cylinder is formed when a graphite sheet is rolled up in such a way that the vector's two end points i.e. the two crystallographically equivalent sites, are superimposed.  $m = 0$  for all zig-zag tubes and  $n = m$  for all armchair-type tubes. All carbon nanotubes can be described by two figures  $(n,m)$ .

Carbon nanotubes can have either metallic or semiconducting properties depending on their diameter and helicity, as described by White C.T, Robertson D.H, and Mintmire J.W, Phys. Rev. B47, pp5485-5488, 1993; "Abstract of Second C60 Symposium", Endo M, Fujiwara H, Fukunaga E, Japan Chemical Society, Tokyo, pp101-104, 1992. To have metallic properties:

$$2n + m = 3q$$

where  $q$  is an integer. All  $(n,n)$  carbon nanotubes and a third of all  $(n,m)$  carbon nanotubes, where  $n$  is not equal to  $m$ , have metallic properties.

According to theoretical models, carbon nanotubes are one-dimensional ballistic conductors whose resistance does not depend on the mean free path between electron collisions. The resistance of these ballistic one-

dimensional conductors is therefore independent of their length and evidence supporting this is available from many experiments.

Carbon nanotubes have extreme mechanical properties such as high tensile strength and flexibility. Conduction losses are low in the direction of the tube's length and the tubes have low density. They are environmentally friendly and heat-and-cold resistant. Multi-layer fullerenes exist where a smaller fullerene structure is contained in a larger fullerene structure. These spherical or tubular fullerene structures are called multi-wall fullerenes. All of the hitherto mentioned fullerene structures are produced naturally when lightning strikes an object containing carbon.

To produce fullerenes synthetically, vaporised carbon is cooled and condensed in an inert atmosphere. A carbon source must be heated until carbon is vaporised and one way of doing this is by utilising energy from an electric arc between two carbon electrodes where the electrodes act as the carbon source. Carbon from one or both of the electrodes is eroded away in the vicinity of the electric arc and is vaporised. This must be carried out in an inert atmosphere in order to produce pure carbon nanotubes. The carbon vapour is cooled to enable the growth of fullerene molecules in the vapour. This is achieved by using a carrier gas to transport the carbon vapour to a collector-plate on which fullerene molecules are condensed among graphite soot. This method is described in US 5,227,038 "Electric Arc Process for Making Fullerenes", Smalley et al; and in "Carbon Nanotubes", Ebbesen et al, Annual Review of Materials Science, vol. 24, p235, 1994.

The electric arc method produces a mixture of spherical and tubular fullerenes. Most of the carbon nanotubes produced are multi-wall

nanotubes having at least two concentric layers. Single-wall nanotubes are preferred for electrical applications as they have fewer defects than multi-wall nanotubes, as few as one in a thousand single-wall carbon nanotubes have defects, and are therefore better conductors than multi-wall carbon nanotubes of the same diameter. More particularly, single-wall nanotubes of the armchair type or of the (n,m)-type where  $2n+m=3q$  are preferred due to their metallic conductivity.

It is known that using a mixture of carbon and transition metals from group VI or VIII, for example nickel, molybdenum, cobalt, iron or platinum, in the electric arc method gives an increased yield of single-wall carbon nanotubes. The transition metals and carbon are vaporized simultaneously and the metals act as catalysts as reported in "Single-shell Carbon Nanotubes of 1nm Diameter", Iijima et al, Nature, vol 363, p603, 1993 and "Improving Conditions Toward Isolating Single-shell Carbon Nanotubes", Lambert et al. Chem. Phys. Letters, vol. 226, p364, 1994. The inner cavities of carbon nanotubes can be filled with atoms/molecules of carbon and/or other elements/compounds which was reported in "Fullerenes with metals inside", Chai et al, J. Phys. Chem. vol 95, p7564, 1991, alternatively carbon nanotubes can be doped with potassium or bromine which has been shown to decrease the resistance of carbon nanotubes (see "Carbon nanotubes as molecular quantum wires", Dekker S, Physics Today, p 22, May 1999).

An alternative carbon nanotube production method is pyrolysis, for example the catalytic pyrolysis of acetylene within an aluminium oxide template is described in WO 99/25652. The aluminium oxide template is produced by anodizing a 99.99% pure aluminium substrate in a suitable acid bath. The aluminium oxide template contains uniform parallel pores in

which a metal catalyst is precipitated, electrochemically for example. Carbon nanotubes are generated by the pyrolysis of a hydrocarbon or carbon monoxide gas inside the pores where there is at least one open end of a carbon nanotube at the aluminium oxide/air interface. The outer diameter of the carbon nanotubes formed corresponds to the diameter of pores in the template.

One method of producing single-wall carbon nanotubes is to use one or more lasers to vaporise a carbon source containing one or more transition metals in a furnace at around 1200°C. The laser-vaporisation method is better than the electric arc method in that it allows better control of the process. The process can be driven continually and it gives a higher yield of single-wall carbon nanotubes. About 80% of the deposited material consists of carbon nanotubes. Furthermore, the carbon nanotubes are purer and of better quality. (See Guo T, Nikolaev P, Thess A, Colbert D.T, Smalley R.E, Chem. Phys. Lett. 243, p49, 1995.

When they condense, single-wall carbon nanotubes have a tendency to form groups containing 10 to 1000 parallel single-wall carbon nanotubes. These so-called ropes, have a diameter of 5-20 nm. Carbon nanotube ropes exhibit two-dimensional triangular geometry and it is believed that the carbon nanotubes are held together by Van der Waals forces. The ropes are mainly metallic and the (10,10) tube-type is usually the dominating component of the ropes.

In WO 98/39250 Smalley *et al* suggest a method for producing continuous metallic carbon nanotube fibres at least 1 mm in length, containing over  $10^6$  single-wall carbon nanotubes having lengths between 50 and 500 nm. The continuous fibres are produced in complex processes in which fibres



grow from an ordered microscopic arrangement of pure single-wall carbon nanotubes on a substrate. Once the substrate with the carbon nanotubes has been prepared, an end-cap from the uppermost end of the carbon nanotubes is removed by oxidation and the carbon nanotubes are then put into contact with a metal catalyst. Vaporised carbon, which is produced by laser vaporisation of graphite, for example, reacts with the open ends if they are heated to between 1100-1300°C. The apparatus in which the continuous metallic carbon nanotubes are produced has to be designed to ensure that the carbon nanotubes' open ends are always situated in the zone in which they can grow.

Medium- to high-voltage power cables (1kV or higher) comprise one or more conductors normally surrounded by an inner semiconducting layer, a layer of insulation and an outer semiconducting layer around said insulating layer. A thicker layer of insulation must be used for high-voltage applications, which increases the diameter of the cable.

Potentially very high current densities (over  $1 \times 10^6$  A/cm<sup>2</sup>) can be obtained in individual carbon nanotubes, which means that a conductor consisting of carbon nanotubes can be made to be extremely compact. It is possible to optimise carbon nanotubes' electrical properties by varying their diameter, the number of concentric layers and their helicity to adapt their electrical properties as required. Wang and de Heer, in the "Symposium on Energy Landscapes in Physics, (session WC35.02) March 1999, reported that electrons are conducted through carbon nanotubes (up to 5 µm long) without generating heat at room temperature. Today's superconductors have to be cooled down to very low temperatures in order to achieve current densities similar to those attained in individual carbon nanotubes.

Electric field strength is defined as the force that is experienced by unit charge. The field strength can be determined with the help of field lines. The more dense the field lines, the greater the field strength. If copper and aluminium conductors in medium- and high-voltage cables are replaced by carbon nanotube fibres as suggested by Smalley *et al* certain problems would arise. The conductor's small radius would lead to an extremely high field in the vicinity of the conductor, probably higher than what conventional insulation materials could endure. The conductor's small size would bring about a very high thermal strain on the insulation material in the vicinity of the conductor interface, which could cause the material to melt and/or break down quickly.

## SUMMARY OF THE INVENTION

One aim of the present invention is to provide a power cable, having one or more conductors, with low conduction losses and being able to carry high current densities. Another aim is to provide a power cable in which the risk of cavities and pores in the cable's insulation system, which can lead to partial discharges at high field strengths, is minimised/eliminated. Another aim is to minimise/eliminate problems arising due to the expansion coefficients of different materials used as insulation and semiconducting layers. A further aim is to control the current in said power cable.

These objects of the invention are achieved by utilising a power cable including at least one conductor comprising nanostructures arranged in a matrix. The term nanostructures includes all structures having a diameter in the range 0.1 to 100 nm. This includes structures such as open and closed, single- and multi-wall nanotubes, fullerenes, nanospheres,

nanoribbons, nanoropes and nanofibres as well as nanotubes, nanoropes or nanofibres woven, plaited or twisted into a layer or a sheath.

It is advantageous for a conductor to have high mechanical strength, low conduction losses, low density, high heat-and-cold resistance and to be environmentally friendly and easy to recycle. Carbon-based material fulfils these demands. One way of solving the problems mentioned in the background of the invention concerning the breakdown of insulation material around a small nanostructure is to design a conductor having substantially homogeneously distributed individual nanostructures in a matrix. If the nanostructures are in contact with each other, the matrix contains up to about 98 volume % nanostructures. If the nanostructures are dispersed in a metal matrix, the matrix contains less than 98 volume % nanostructures.

It is to be understood that matrix means a material in which individual nanostructures are arranged. The matrix is for example a polymer, ceramic, metal, non-metal, gel, fluid, an organic or inorganic material. The matrix can even comprise a thin layer of metal, gold for example, which wholly or partly covers the nanostructures providing metallic contact between adjacent nanostructures. A metal matrix decreases the contact resistance and improves the conduction between individual nanostructures, which leads to conductors having low conduction losses. Carbon-containing material, such as graphite, amorphous carbon and other fullerenes, can also be used as matrix material. Utilising carbon-containing material does not adversely effect the conductor's conductivity and it leads to a simple and cost-effective process for the production of conductors because further treatment of the powder deposited on production of carbon nanostructures is not necessary.

The carbon nanotubes used are, for example, metallic, semiconducting, of the (n,n) or (n,m) varieties, single-wall, multi-wall, doped with an alkali metal such as potassium or a halogen such as bromine to reduce the resistance of the nanostructures, or contain atoms of carbon or other elements in their inner cavities. The nanostructures utilised are either one, or a combination of two or more of the varieties mentioned above. The length of individual nanotubes is preferably at least 1  $\mu\text{m}$  in order to utilise the ballistic conductivity of the nanotubes.

The nanostructures are substantially homogeneously dispersed in a matrix. The nanostructures can be intercalated i.e. ions/atoms/molecules are inserted or incorporated between nanostructures such as nanotubes, nanoropes or nanofibres. The nanostructure material is intercalated with metals, for example, to provide metallic contact between individual single-wall carbon nanotubes, or other substances to create interstices that decrease the interaction between nanostructures. Alkali metals, in group II of the periodic table, work well as intercalants. They have a valence electron i.e. a single electron in the atom's outer shell. The valence electron is easily donated due to the atom's low ionization energy and this creates a positive ion as well as a charge carrier. There are other intercalants that accept charge carriers and intercalants that decrease the interaction between individual nanostructures.

By designing a conductor comprising of substantially homogeneously dispersed individual nanostructures in a matrix, the effective current density will be lower and the electric field is spread out over a greater area which decreases the concentration of the electric field in the vicinity of the conductor, significantly increasing the interface between the nanostructures and the surrounding material.

If the conductors are extruded, a majority of the nanostructures are oriented along the length of the conductors due to the flow pattern through the extrusion nozzle. The conductors can also be produced by compressing nanostructures with matrix material, alternatively by melting matrix material with nanostructure material under high pressure or by casting. A method similar to that for producing superconductors is also possible, i.e. nanostructures are mixed with matrix material in powder form, the mixture is pressed into a metal tube, heat treated and the substance is drawn and/or rolled into wire.

Another way of solving the problem with breakdown of insulation material and of avoiding a high electric field around the conductor is by utilizing a hollow conductor i.e. the conductor/s are arranged in one or more concentric layers. This increases the conductor's outer radius, which decreases the electric field concentration as well as increasing the area. The volume within the hollow conductor/s is filled with insulation or matrix material through which heat is conducted, or it contains reinforcement comprising steel, kevlar or carbon nanostructure-containing-material which increases the cable's tensile strength, and/or a single/multi-mode optic fibre. The reinforcement can also be used in conjunction with solid, i.e. non-hollow, conductors. These ways of producing carbon nanostructure-based conductors require a relatively low volume of nanostructures in order to attain a desired current density.

In another preferred embodiment of the invention, multi-wall nanostructures having a small diameter, less than 5nm, and preferably just two layers are utilised. The outer layer of these nanostructures acts as a shield for the inner conducting layer.

A cable's insulation material comprises, for example, a thermoplastic such as low/high-density polyethylene, low/high-density polypropylene, polybutylethylene, polymethylpentene, a fluoropolymer, such as Teflon<sup>TM</sup>, polyvinylchloride, crosslinked material, such as crosslinked polyethylene, rubber material, such as ethylene propylene rubber or silicone rubber. The semiconducting layers are constituted of the same material as the insulation material but contain conducting material such as carbon black, metal or nanostructures such as carbon nanotubes with semiconducting/metallic properties. The individual layers of the insulation system are in contact with each other and in a preferred embodiment of the invention they are joined by the extrusion of radially adjacent layers. It is important to minimise the risk of forming cavities or pores in the insulation system, which can lead to partial discharges in the insulation material at high electric field strengths.

If one of the above mentioned (insulation) materials is used as matrix material, it would be possible to produce the whole cable from the same base material. Polyethylene can for example be used for the insulation, in the semiconducting layers by including some conducting material, such as carbon black, as well as matrix material. This eliminates the problem of attaining good adhesion between different materials, minimises problems due to the expansion of different materials in the presence of a temperature gradient and simplifies the cable production process. All of the layers within the cable, i.e. the insulation, the semiconducting layers, and outer covering are extruded together around the conductor/s. In order to produce a cable according to the present invention, the conductors, or even the whole cable are extruded in a simple extrusion process. The power cable's components are extruded, or wound, in radially adjacent

layers and then preferably, the cable is vulcanised to impart improved elasticity, strength and stability.

A further advantage of the present invention is that the current in the cable can be controlled in several ways. One way of controlling the current is to apply pressure to the cable to improve/worsen the contact/conductivity between the nanostructures or between the matrix material and the nanostructures in the conductor. Another possibility is to influence the nanostructures' or matrix material's resistance using a magnetic field, alternatively by utilising the magneto-resistive effect of the matrix material. A further possibility is to utilise the piezoelectric effect of the matrix material. Furthermore electromagnetic waves such as microwaves or light can be utilised, to change the conductivity of the conductor material. A further possibility is via diffusion, to utilise hydrogen absorption by nanostructures, which influences their conductivity. A further possibility is to change the conductor's temperature.

## **BRIEF DESCRIPTION OF THE DRAWING**

A greater understanding of the invention may be obtained by reference to the accompanying drawing, when considered in conjunction with the subsequent description of the preferred embodiments, in which;

Fig 1 shows a three-dimensional view of a power cable having three conductors according to a first embodiment of the present invention

Fig 2 shows a three-dimensional view of a power cable having four conductors according to second embodiment of the present invention

Fig 3 shows a three-dimensional view of a power cable having one conductor according to a third embodiment of the present invention.

Fig 4 shows a three-dimensional view of a coaxial power cable having hollow conductors and an optic fibre at its centre.

## **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The present invention concerns all types of electric cables to supply electricity, for both DC and AC transmission, for supplying machines as well as for signal transmission within the communications field. The present invention particularly concerns power cables for high frequency applications i.e. greater than 1kHz, more particularly greater than 10kHz. Some preferred embodiments of the invention will now be described.

A power cable 1 according to a first embodiment of the present invention is shown in figure 1. It comprises, two copper, or aluminium, conductors 10; a third conductor 11 containing nanostructures such as carbon nanotubes; insulation 12; a concentric screen 13 of metal wire for example; and an outer covering 14. It is possible to replace the screen of metal wire 13 with a braided screen, metal foil, tape or a material containing nanostructures.

Figure 2 shows a power cable 2, which comprises four conductors where one conductor 21 contains nanostructures and the other conductors 20 consist of copper or aluminium, for example. The conductors do not have to be of the same size, as shown. One of the conductors 20,21 is earthed. The conductors are surrounded by insulation material 22 and an outer covering 23.



The electric load on the cable's insulation material is decreased if semiconducting layers are placed around the insulation material. The semiconducting layers form equipotential surfaces and the electric field is relatively evenly spread out over the insulation material. In this way the risk of breakdown of the insulation material due to local concentrations of the electric field are minimised. The outer semiconducting layer in a cable can be maintained at a controlled potential, for example earth potential. Semiconducting layers are placed at both sides of the insulation material.

Figure 3 shows a power cable 3, with one conductor 30, containing nanostructures, which is surrounded by an inner semiconducting layer 31, insulation 32, and an outer semiconducting layer 33, which can be earthed and a screen of metal wire 34. The cable comprises, inner and outer semiconducting layers 31,33, containing carbon nanotubes for example.

Several concentric conductors, each having it's own insulation system can be incorporated into a power cable comprising insulation and semiconducting material as shown in figure 4. Figure 4 shows a cable 4, comprising a hollow conductor 42, that contains nanostructures, which is surrounded by a first semiconducting layer 43, insulation 44, a second semiconducting layer, 45, a concentric conductor 46, that contains nanostructures, a third semiconducting layer 47, insulation 48, a fourth semiconducting layer 49, and an outer covering 50. The hole in the centre of the cable 41 is, for example, filled with insulation material, nanostructure-containing material, reinforcement or a single/multi-mode optic fibre 40. Optic fibres are not susceptible to electric or magnetic interference, which allows their incorporation into a power cable. They are arranged to transmit optical signals and/or monitor the cable. The

concentric conductor that contains nanostructures 46 can be replaced with copper or aluminium wires, a metal foil or tape.

The conductors 10,11,20,21,30,42 can have cross-sections other than those shown in the examples, and more than one conductor may contain nanostructures. Those conductors 11, 21, 30, 42, 46 which contain nanostructures contain substantially homogeneously dispersed individual nanostructures in a matrix.

In a preferred embodiment of the invention a power cable is designed as shown in figure 3 where the conductor 30 contains 98 volume % of single-wall carbon nanotubes at least 1  $\mu$ m in length in a cross-linked polyethylene matrix. The semiconducting layers 31 and 33 contain particles of carbon black dispersed in cross-linked polyethylene. The insulation 32 comprises cross-linked polyethylene. The screen 34 comprises copper wire and the outer covering 35 comprises cross-linked polyethylene.

Alternative production methods of power cables according to the present invention, other than those exemplified in this document, are possible. The cable's insulation system and the semiconducting layers can be wound onto the conductor/s. One example of an insulation system is that used in conventional cellulose-based cables where cellulose-based material or synthetic paper is wound around the conductor/s. Other examples of insulation systems are those containing a solid porous, fibrous, or laminated structure impregnated with a dielectric substance, such as mineral oil which fills the pores/cavities in the insulation system.

## CLAIMS

1. A power cable 1,2,3,4, comprises one or more conductors 10,11,20,21,30,42 surrounded by insulation material 12,22,32,44,48 where at least one conductor 11,21,30,42 contains nanostructures, **characterized in that** the conductor containing nanostructures comprises a matrix in which the nanostructures are arranged.

2. A power cable according to claim 1, **characterized in that** the matrix comprises at least one of the following: a polymer, ceramic, metal, non-metal, fluid, gel, carbon-containing material such as graphite, amorphous carbon or fullerenes, an organic or inorganic material or a combination of said materials.

3. A power cable according to claims 1 or 2, **characterized in that** the individual nanostructures are substantially homogeneously dispersed in the matrix.

4. A power cable according to any of the previous claims, **characterized in that** the nanostructures comprise multi-wall nanotubes having two layers and a small outer diameter.

5. A power cable according to any of the previous claims, **characterized in that** the nanostructures comprise individual nanotubes are at least 1  $\mu\text{m}$  long.

6. A power cable according to any of the previous claims, **characterized in that** the matrix contains less than 98 volume % nanostructures.

7. A power cable according to any of the previous claims, **characterized in that** the matrix comprises less than 95 volume % nanostructures.
8. A power cable according to any of the previous claims, **characterized in that** the matrix comprises less than 90 volume % nanostructures.
9. A power cable according to any of the previous claims, **characterized in that** the matrix comprises less than 80 volume % nanostructures.
10. A power cable according to any of the previous claims, **characterized in that** the matrix comprises less than 70 volume % nanostructures.
11. A power cable according to any of the previous claims, **characterized in that** the matrix comprises less than 50 volume % nanostructures.
12. A power cable according to claim 4, **characterized in that** the nanostructures are intercalated.
13. A power cable according to claim 12, **characterized in that** the intercalant is a substance which decreases the interaction between individual nanostructures.
14. A power cable according to claims 12 or 13, **characterized in that** the intercalant comprises an acceptor or a donator of charge carriers.
15. A power cable according to any of the previous claims, **characterized in that** the nanostructures comprise single-wall nanotubes, multiwall nanotubes, or a combination of both.

16. A power cable according to any of the previous claims, **characterized in that** the nanotubes are metallic, semiconducting, or a combination of both.

17. A power cable according to any of the previous claims, **characterized in that** the nanotubes are of the type (n,n), or (n,m), or a combination of both.

18. A power cable according to any of the previous claims, **characterized in that** the nanostructures' inner cavities are filled with atoms of carbon or other elements.

19. A power cable according to any of the previous claims, **characterized in that** the nanostructures are doped with an alkali metal or a halogen.

20. A power cable according to any of the previous claims, **characterized in that** the conductors containing nanostructures in a matrix are extruded whereby the majority of individual nanostructures are oriented in the direction of the conductor's length.

21. A power cable according to any of the previous claims, **characterized in that** the conductors 42, 46 containing individual nanostructures in a matrix are formed as concentric layers.

22. A power cable according to claim 21, **characterized in that** the concentric layers enclose a volume 41, which contains at least one of the following: insulation material, matrix material, reinforcement, a single/multi-mode optic fibre 40.

23. A power cable according to claim 22, **characterized in that** the reinforcement comprises steel, kevlar or nanostructures.

24. A power cable according to claim 22, **characterized in that** the single/multi-mode optic fibres are arranged to transmit optic signals and/or to monitor the cable.

25. A power cable according to any of the previous claims, **characterized in that** the nanostructures comprise nanotubes, ropes or fibres that are woven, plaited or twisted to form a layer or a sheath.

26. A power cable according to any of the previous claims, **characterized in that** the conductors are surrounded by a semiconducting layer 31,33,43,45,47,49.

27. A power cable according to claim 26, **characterized in that** the semiconducting layer contains nanostructures.

28. A power cable according to any of the previous claims, **characterized in that** the insulation 12,22,32,44,48, comprises at least one of the following: a thermoplastic, polybutylethylene, polymethylpentene, a fluoropolymer, mica, polyvinylchloride, cross-linked material, rubber material.

29. A power cable according to any of claims 26-28, **characterized in that** it comprises at least one semiconducting layer whereby the semiconducting layer comprises the same material as the insulation and contains conducting material.

30. A power cable according to claim 29, **characterized in that** the conducting material is carbon black, a metal, or contains nanostructures.

31. A method for producing a power cable comprising at least one conductor where at least one conductor comprises nanostructures and where said at least one conductor is surrounded by insulation material, **characterized in that** the method comprises the steps of embedding nanostructures in a matrix, forming the material into at a conductor and surrounding the conductor with insulation material.

32. A method according to claim 31, **characterized in that** a semiconducting layer is arranged at each side of the insulation material.

33. A method according to claim 32, **characterized in that** said at least one conductor, semiconducting layers, insulation material, matrix material and an outer cover are formed into a cable by extrusion.

34. A method according to claim 32, **characterized in that** said semiconducting layers, insulation material, matrix material and outer cover are wound onto said at least one conductor.

35. A method according to any of claims 31-34, **characterized in that** all the components of the power cable comprise the same base material and are extruded together.

36. A method according to any of claims 31-35, **characterized in that** said cable is vulcanised.





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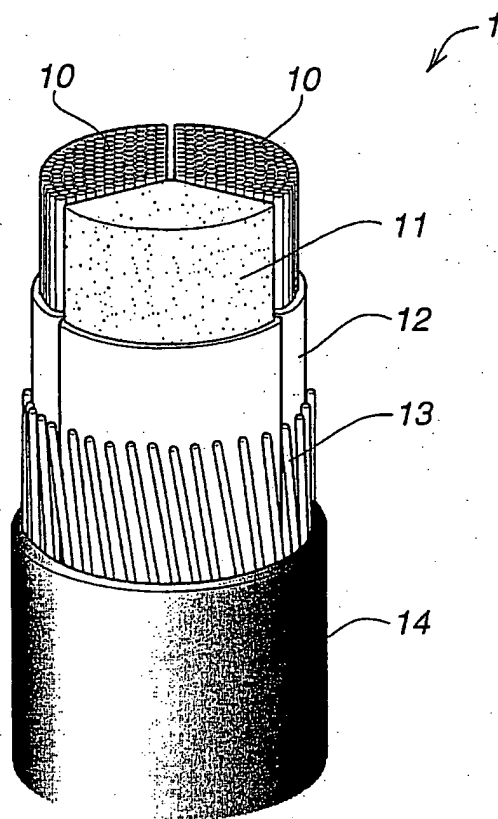


Fig. 1

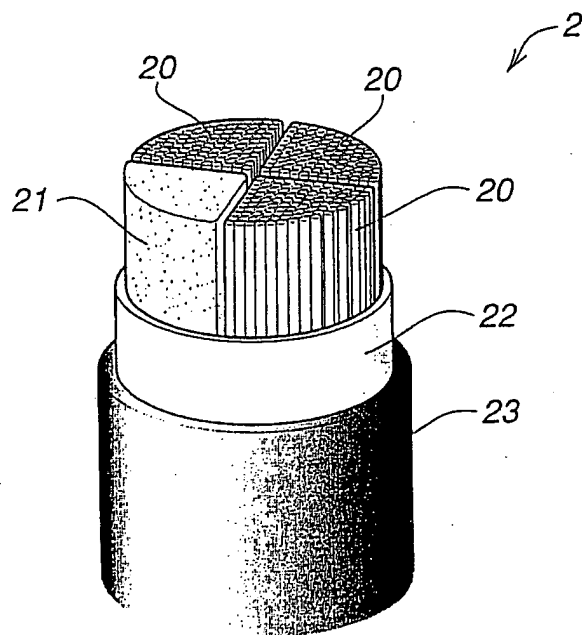


Fig. 2

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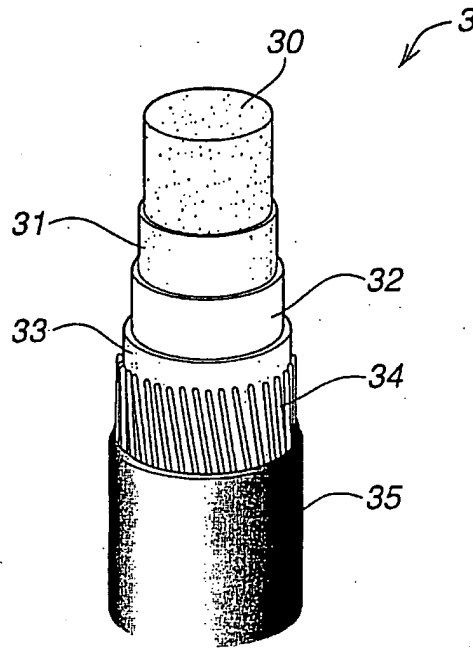


Fig. 3

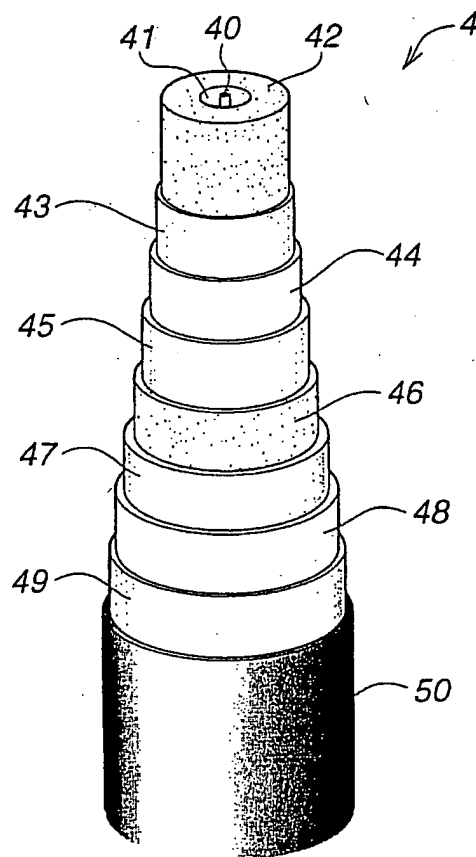


Fig. 4

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 01/00696

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H01B 1/04, C01B 31/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO INTERNAL

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9839250 A1 (WILLIAM MARSH RICE UNIVERSITY), 11 Sept 1998 (11.09.98), page 46, line 1 - page 48, line 29; page 49, line 1 - page 50, line 13; page 62, column 3 - page 68, line 9 --	1-43
X	US 5627140 A (KRISTIAN FOSSHEIM ET AL), 6 May 1997 (06.05.97), column 1, line 1 - line 25; column 2, line 35 - line 50; column 5, line 50 - column 6, line 4 --	1-43
X	US 5530206 A (LYDIE ROBERT ET AL), 25 June 1996 (25.06.96), column 1, line 1 - column 2, line 67 --	1-43

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

## \* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

14 June 2001

Date of mailing of the international search report

19-06-2001

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 01/00696

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5698140 A (LOWELL D. LAMB ET AL), 16 December 1997 (16.12.97), column 2, line 40 - column 3, line 18; column 6, line 61 - line 65 --	1-43
P,A	EP 1052654 A1 (UNION CARBIDE CHEMICALS & PLASTICS TECHNOLOGY CORPORATION), 15 November 2000 (15.11.00) -- -----	1-43

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Information on patent family members

28/05/01

International application No.  
PCT/SE 01/00696

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